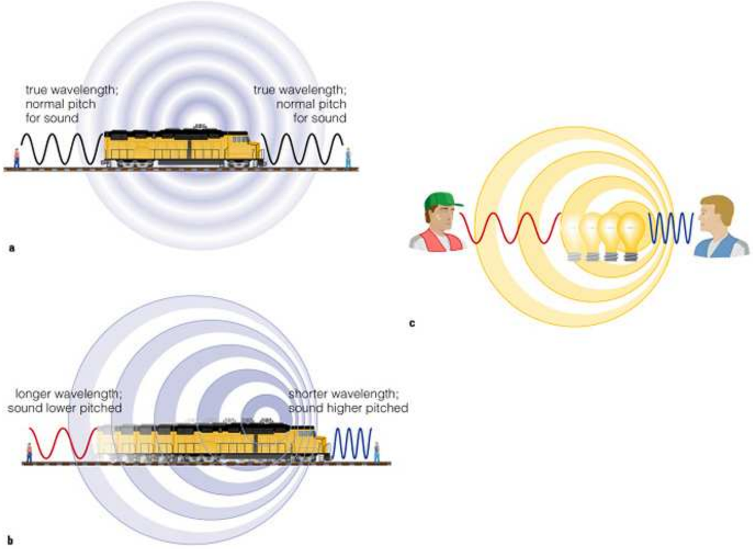
Lecture 22

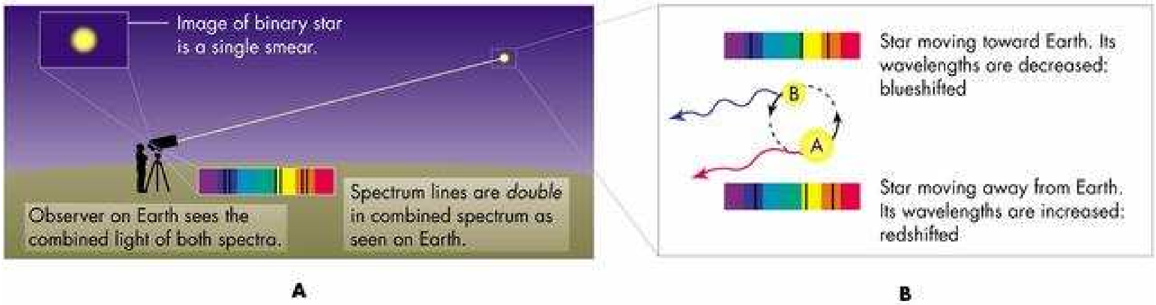
1. Measuring a star’s motion (Doppler effect)

Emission lines also tell you how something is moving towards or away from you. We can do this through the Doppler Effect.

The Doppler Effect is familiar from every-day life from when you hear a train whistle or police car siren. When the siren comes towards you, the sound is higher pitched, but when it goes away from you, it's lower pitched.

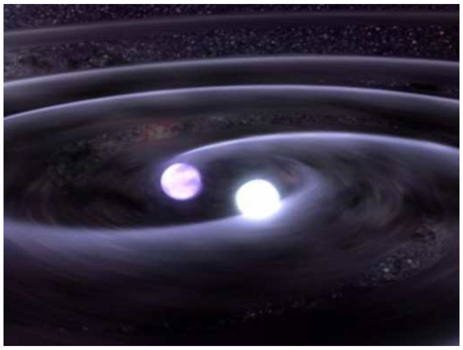
Something very similar happens with light. If something moves *towards* you, then its waves of light will come to you closer together, and it will appear to have a shorter wavelength. So you will see things moving towards you as *blue-shifted*. Likewise, something moving *away* from you will appear *red-shifted*. This is the Doppler Shift. The *amount* of the shift in wavelength is proportional to how fast the thing is moving.





From the series of spectra, astronomers can measure the orbital speed of the stars and their period which will result in the size of the orbit and mass of the star.

2. Binary Stars



Looking through a telescope at the stars there is very little information we can gain from them. To be sure, we know what color they are and we can see that some are more luminous than others. If we use a spectrograph we can tell what elements they are made up from. From these facts alone, it is difficult to tell just how much mass they contain. By looking at pairs of stars that orbit one another we can try to answer the question, how much mass do the stars have?

Binary stars can be of two fundamental types:

- Visual Binaries
- Optical Doubles

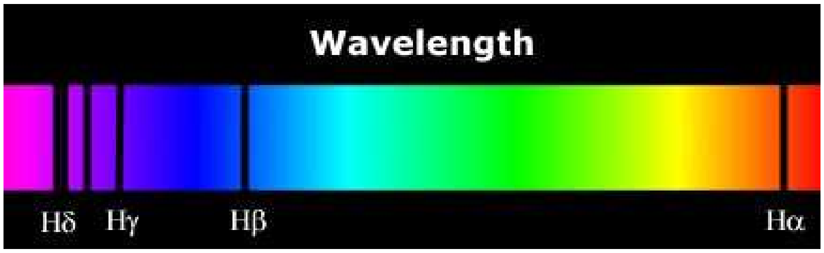
Visual Binaries are stars that are clearly gravitational associated with one another. They orbit each other around a common center called the **barycenter**. Visual binaries can be seen optically through a telescope. Only a small portion of binary stars are visual binaries. In order to see a visual binary, the stars must be separated by fairly wide distances, and the orbital periods are usually very long.

Optical Doubles are stars that appear to lie close together, but in fact do not, they only appear to us from our earthly observation to be close together. One of the stars in the pair is actually behind the first star and very far away. The stars of an optical double are not gravitationally bound.

William Herschel began looking for optical doubles in 1782 with the hope that he would find a measurable parallax, by comparing a close star to the more distant star in an optical double. Herschel did not find any optical binaries, but he did catalog hundreds of visual binaries. In 1804 Herschel had so many measurements of visual binaries that he concluded that a pair of stars known as Castor were orbiting one another. This was an important discovery, because it was the first time observational evidence clearly showed two objects in orbit around each other outside of the influence of our own Sun and Solar System.

Spectroscopic Binary

It is also possible to detect binary stars using a spectroscope. If two stars are orbiting each other they will both produce a spectrum. If the stars are close to being the same brightness it is possible to see different spectral lines from both stars. These stars are of particular interest because it can be used to determine the radial velocity of the orbit of the two stars. Stars appear red shifted when receding away from the earth and blue shifted as they approach. This effect is caused by the Doppler effect which distorts arriving light waves from the stars depending on the direction if their motion. A Spectroscopic binary will alternate between blue and red shifted spectral lines.



Spectroscopic binaries are not detectable if we are seeing the star head on because no Doppler shifts would be present in the spectrum.

If the Doppler shifts are present in a single line of the spectrum, we are seeing the light from only one star and we call this a single-line spectroscopic binary. If we can see the light from both stars the Doppler shifts will alternate, split and merge depending on the positions of the two stars in their orbits. This is called a double-line spectroscopic binary.

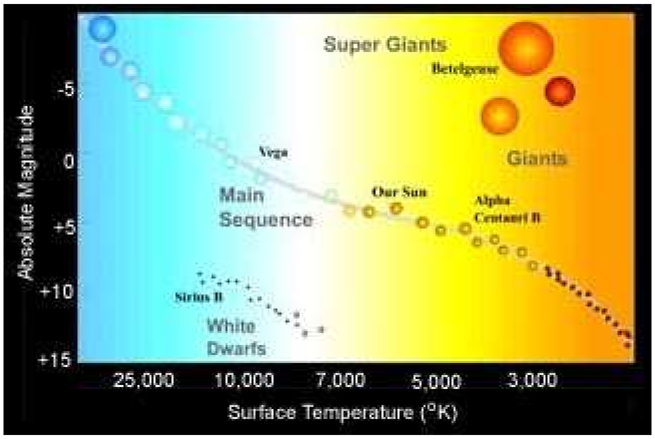
One very important detail, we do not know how the orbits of the two stars are inclined to earth. This inclination could be any angle, for that bit of information we have to go back to visual methods in order to see the individual stars to determine the inclination of their orbits relative to earth. Even so we can not for certain determine the true inclination of the orbit so our mass calculation is only a lower limit to the masses of the two stars.

Radial velocities permit astronomers to compute the total mass for the two stars, they do not provide the masses for the individual stars and other methods must be used to make that determination

3. Summary of stellar properties

Quantity	**Method**
Distance	Parallax (triangulation)
Temperature	Wien’s law
Luminosity	Inverse square law (from brightness and distance)
Composition	Spectral lines
Radius	Stephan-Boltzmann law
Mass	Kepler’s 3rd law
Radial velocity	Doppler shift

4. Hertzsprung-Russell diagram (H-R diagram)



Are all stars the same? Not in the least! Some stars are just beginning to form in nebulae, others are enjoying middle age along the main sequence, and some have begun to die. The life cycle of a star can be compared to the life cycle of humans. The Hertzsprung-Russell Diagram is a tool that shows relationships and differences between stars. It is something of a "family portrait." It shows stars of different ages and in different stages, all at the same time. But it is a great tool to check your understanding of the star life cycle.

In the Hertzsprung-Russell (HR) Diagram, each star is represented by a dot. There are lots of stars out there, so there are lots of dots. The position of each dot on the diagram tells us two things about each star: its luminosity (or absolute magnitude) and its temperature.

The vertical axis represents the star’s luminosity or absolute magnitude. Luminosity is technically the amount of energy a star radiates in one second, but you can think of it as how bright or how dim the star appears. Depending upon the textbook you use, the labels on the HR diagram could be a little different. **Luminosity** is a common term, as is **absolute magnitude**. Absolute magnitude is the intrinsic brightness of a star. In either case, the scale is a "ratio scale" in which stars are compared to each other based upon a reference (our sun).

The horizontal axis represents the star’s surface temperature (not the star’s core temperature – we cannot see into the core of a star, only its surface)! Usually this is labeled using the Kelvin temperature scale. *But notice*: In most graphs and diagrams, zero (or the smaller numbers) exist to the left on the diagram. *This is not the case here*. On this diagram, the higher (hotter) temperatures are on the left, and the lower (cooler) temperatures are on the right. Some HR diagrams include the color of stars as they can be seen through filters on spectrophotometers. This is also a "ratio scale."

So how do you read the HR diagram? Well, let’s look at some basic regions on it. A star in the upper left corner of the diagram would be hot and bright. A star in the upper right corner of the diagram would be cool and bright. The Sun rests approximately in the middle of the diagram, and it is the star which we use for comparison. A star in the lower left corner of the diagram would be hot and dim. A star in the lower right corner of the diagram would be cold and dim. Are there any stars that seem out of place? For example, are there any stars that are really hot but not very bright? Are there any stars that are not very hot but they shine very brightly? What do you think could account for these differences in stars that do not fit the pattern? Stars that *do fit* the pattern are called **main sequence** stars. Let’s look at those before we deal with the exceptions.

Most of the stars lie within a region called the main sequence. It looks kind of like a curved line sloping from the upper-left to the lower-right of the HR diagram. There are some stars that are not on the main sequence, but for now let’s concentrate on the main sequence stars. Why is there a main sequence region anyway? Well, there is a predictable relationship between the brightness and size of a star. This shows up on the HR diagram. We know that hotter things are brighter. A hotter temperature means that more energy is radiated into space. Bigger stars are brighter. A bigger surface area means that more energy is radiated into space. The sun is used as a reference, so let’s use some logic to figure out how this works.